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4 FINAL REPORT

3 CONSTANT AZIMUTH CENTRIFUGE 4

GEORGE C. MARSHALL
SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA

25 CONTRACT NO. NAS8-11856 29

1 THE RUCKER COMPANY 3
JOB 81816

This report takes the form of a month by month historical review of activity during the performance of the contract.

June 1965

Received the contract on June 10th. Planning for the project had been progressing for a few weeks prior to this date. The shaker system was ordered from Ling on June 15th so that it would be on hand when the shaker redesign was ready.

Design work in June consisted of:

a. Layout of the shaker modification and some detail drawing. The design was optimized to include two oil hydrostatic bearings and a gas compensation cylinder with minimum increase in armature weight and with minimum loss of iron in the magnetic path.

b. Selection of the shaker amplifier and accessories, field unit and heat exchanger unit.

c. Layout and stress calculation of the environmental chamber.

d. Design of the shaker suspension system.

e. Selection of vacuum and CO2 systems.

f. Preliminary layout of the constant azimuth table.

g. Preliminary design of the pedestal assembly and main hydrostatic bearings.

h. Provisional layout of the main rotary joint-slip ring package.

i. Selection of the television camera. At this time a Granger camera and a Zoomar lens were selected.

July 1965

The shaker and its auxiliary equipment arrived during the month and was set up in preparation for a pre-modification checkout.

Design activities included:

a. Completion of shaker drawings.

b. Environmental end design and layout in progress.

c. Azimuth end design and layout complete. Detail drawing in progress. Slip ring and rotary joint in design.

d. Hub and pedestal design in progress. This involved considerable design work in optimizing space utilization.

e. Selection of speed readout equipment including the counter.

f. Preliminary work on the control logic and on the shaker compensation electronics.

g. Television system ordered.

h. Tentative location of equipment and utilities for submittal.

<u>August 1965</u>

a. The shaker as received was checked out satisfactorily and modification commenced. The MB manual equalization system was ordered for delivery direct to Huntsville. Some work was done in arranging a test bed for checkout of the modified shaker under simulated loading.

b. Design and detail work on the environmental end was virtually completed. The difficulties involved in arranging hoses and cables to accomodate both positions of the shaker table were satisfactorily overcome.

c. On the azimuth end most detail drawings were completed but some delay was experienced in procuring a satisfactory timing belt. The 6 ft distance between centers necessitated a specially spliced belt. Final detailing was held up until assurance could be received from U. S. Rubber that such a belt could be furnished.

d. The pedestal calculations and layout were completed and the detail drawings were started. Static and dynamic calculations were performed for the rotor in its various modes of operation in order to complete the design of the main hydrostatic bearings.

e. Final selection of the counter and magnetic pickup was made. A

600 tooth precision gear and magnetic pickup were chosen for pulse generation. It was decided to use two synchros operating from 600 tooth gears (at the main hub and at the azimuth table axis) to determine position inaccuracy at the azimuth table.

f. It was decided to use a differential pressure gauge between opposing pads of the upper hydrostatic bearing to indicate the degree of rotor unbalance.

g. The shaker gas compensation system was designed and the electronic position control unit was "bread-boarded" for preliminary tests.

h. Slip ring specifications were written. Inductance and resistance of the shaker slip rings had to be especially low to avoid attenuation in shaker performance.

i. Design of the two hydraulic power units was in progress and the major components were selected.

September 1965

a. All parts of the shaker were completed and the unit was in process of assembly. The test bed was being readied for shaker checkout.

b. Detail drawings were completed on the rotor and parts lists were made; bearings and cylinders were ordered.

c. Pedestal detail and sub-assembly drawings were completed and checked.

d. Design and detailing were completed on the two hydraulic power units and major components, such as the pumps, were ordered.

e. The electrical control schematic was completed as was the control analysis. The counter arrived in house and the console parts were selected.

f. The three slip ring assemblies were ordered.

g. The concrete foundation was designed and drawings were in progress.

h. The piping layouts were nearing completion.

October 1965

During October a visit was made by the Rucker project team (I. C. Begg and W. A. Henry) to the NASA facility at Huntsville during which time the project progress was reviewed and, in particular, the test procedure was discussed.

A deviation to build an arm weighing more than 4000 lbs (for reasons of rigidity and accuracy) was requested and granted provided the Rucker Co. assumed responsibility for damage to the building during installation.

During this meeting, the layout of the enclosure roof was discussed and finalized. It was agreed, at NASA's request, to change the console design from an upright rack enclosure to a lower double section console with more frontal area and less obstruction in visibility of the shaker amplifier behind it. The television monitor was to become a separate unit.

During the visit to Huntsville contact was made with local contractors to establish a bidders list for the installation contract.

During the month work continued on all aspects of design and procurement though some delay was experienced in reworking some of the drawings and re-ordering some of the components as a consequence of decisions made at the meeting.

Design of the foundation and enclosure roof was completed.

All major components (including a timing belt from U. S. Rubber) were ordered.

November 1965

During November the rotor weldment was completed at the Rucker plant ready for machining at Western Gear Corp.

The pedestal parts were being manufactured at Keystone Engineering in Los Angeles. All special parts were ordered from local manufacturers.

Considerable disappointment was experienced in the delivery times quoted by all manufacturers. Lead time had greatly increased since the time of the proposal. It was now apparent that the project would be delayed by several months.

The Granger television camera was cancelled because of their inability to provide proper support bracketry and a Fairchild unit was ordered instead. This unit is far more compact than the Granger and its performance is at least as good.

Mr. Kirby of NASA visited the Rucker facility at the end of November to evaluate progress and to witness tests on the modified shaker; which commenced on Nov. 21st.

During these tests it was found that the original extraction pump drive motor was inadequate for the job and a new unit was built.

The modified shaker was found to perform very well under a simulated 3000 lbs load applied transversely or axially. The following changes were made during the test:

a. The filter pressure drop was found to be excessive and a larger filter was installed.

b. The oil had to be changed for one of higher viscosity.

c. Some development was needed in establishing orifice sizes to provide max load capability with minimum flow over a max temperature range.

d. A modification had to be made to avoid spurious vibration due to oil turbulence through the orifices.

e. The gas diaphragms had to be modified to eliminate leakage and it was found expedient to avoid operation of the diaphragms under zero pressure to prolong their life. These modifications were in progress as the month ended.

December 1965

The month was occupied in manufacture of the main rotor, pedestal and other major parts. Some delays on the part of the vendors.

Modifications were made to the shaker and considerable testing was done.

Power units were ready except for the Denison pump which was late.

The control console was held up pending arrival of the frames.

It was decided to re-design the azimuth slip rings so that the brushes rode on the top of the rings instead of on their periphery. In this way electrical noise due to cyclic variations of brush pressure in the g-field would be avoided.

January 1966

The required assembly drawings were submitted to NASA, 12-21-66. Miller & Berry, Inc. were selected as contractors for the installation at Huntsville.

Shaker tests continued intermittently during the month after delays due to minor modifications.

Rotor assembly proceeded during the month, but some delay was experienced due to late arrival of some machined parts and some rework required from vendors. The timing belt pulleys had to be remade because, through a minunderstanding, were made with the wrong pitch. The pedestal parts were nearing completion at Keystone and the hydraulic power units were being assembled. The Denison pump had not yet arrived.

The control console still awaited the arrival of the new frames. The system was simulated on the Analog computer and the Compensation network was designed. The television camera arrived and was checked out.

During this month plans were made for a test bed at the Rucker plant in order to run the machine at low rpm to check the control operation.

February 1966

Shaker testing was completed after arrival of the new diaphragms from Bellofram. The tests were entirely satisfactory and the shaker design was proved.

The rotor assembly was virtually completed and the environmental table tilting mechanism was checked.

The inner shell of the environmental chamber was vacuum tested on the environmental table. The suction hose was connected directly to the table inlet (no rotary joint). A vacuum of 8 microns was achieved with the shaker in position and 2 microns was reached with the plug in place of the shaker.

The outer shell was then added to the chamber and the foam insulation was installed.

The pedestal was also being assembled separately from the rotor so that the hub could be driven up to speed to check the hydrostatic bearing characteristics. This could not be done in the plant with the rotor in place because speed would be limited by safety consideration.

The rotary joints were assembled but had to be reworked because there was too much squeeze on the sealing rings. Two of the three slip ring assemblies arrived in house. The hydraulic power units were completed after the arrival of the Denison pump. The console frame arrived and the console was assembled.

The concrete was poured at Huntsville and work ceased at the site pending arrival of the machine.

<u>March 1966</u>

Rotor and pedestal assemblies were individually complete. The power units were completed and temporarily piped up to the pedestal which was bolted to a steel beam foundation erected on the shop floor. The control console was connected up to the tachometer assembly on the pedestal and the counter to the magnetic pickup. The hub was then run up to the maximum speed of 221 rpm (representing 100 G's). The hydrostatic bearings performed satisfactorily and the turning torque agreed with the design figures.

Of course, a small cyclic pad pressure variation was recorded due to unavoidable ovality (tenths of a thousandth) in the hub bore. This pressure variation is harmless and should be ignored when estimating pressure variation due to rotor unbalance.

A visit was made at this time by Messrs. Kirby and Combs of the NASA facility and they were able to witness the pedestal test.

The rotary joints were pressurized and rotated on the lathe. They were satisfactory and leak tight in all respect except for high pressure nitrogen (1000 - 1500 psi). At this pressure intermittent leakage occured past the sealing rings. After some rework the problem was still present and it was decided to assemble the entire machine with the rotary joint in place so that the centrifuge systems could be checked out. Then the machine could be shipped and erected on site while the rotary joints were being modified at the Rucker plant.

April 1966

April was occupied with intensive testing of the complete machine at the Rucker plant. The rotor was assembled to the hub and the shaker to the rotor. The shaker skip rings were mounted on a temporary spacer above the rotor so that power could be supplied to the shaker while the machine was rotating.

In checking out the shaker in the vertical mode it was found that some modification had to be made in the extraction pump oil lines to reduce pressure drop. The lines were enlarged and double passages were used through the rotary joint. It was also necessary to use a larger heat exchanger on the bearing power unit in order to keep oil temperature below 100°F (necessary to avoid orifice turbulence at the shaker bearings). These modifications were made during the checkout. The shaker was able to meet its specified performance in the vertical mode with no apparent power loss through the slip rings. This test, combined with the shaker loading tests earlier, confirmed that the shaker system was adequate.

Tests were then started in the horizontal mode but these were unfortunately halted when the shaker coil parted company with the shaker armature. The coil is expoxied to the magnesium armature by Ling. Coil separation has occurred on rare occasions with shakers operating under standard conditions. Looseness of the coil upper connection had been noticed earlier, (before load simulation tests had begun) and extra epoxy (supplied by Ling) had been added. Some delay was experienced because the shaker had to be dismantled and the armature returned to Winchester, Mass for replacement of the coil. The job was well done and the trouble is unlikely to recur.

Toward the end of the month tests were completed and the machine was dismantled ready for painting, crating and shipping to the site.

May 1966

During May the centrifuge was painted, crated and shipped to Huntsville where installation commenced. The shaker and the rotary joints were retained at the Rucker plant for completion before shipment.

The shaker was re-assembled and shipped soon afterwards.

The rotary joints were polished and plated in the bores and retested. Leakage of high pressure gas still occurred despite several further modifications.

June 1966

Installation of the machine at Huntsville was completed as far as possible pending arrival of the rotary joints.

The rotary joints were modified to use 3/16" thick quad rings instead of the 1/8" ones previously used. This entailed re-machining all the grooves on the spindles and it also caused some delay while the quad rings were procured.

This modification made a significant improvement in the high pressure gas passages but intermittent blow-by still occurred at pressures over 1200 psi.

At this stage, since only one gas passage carried gas at over 1000 psi, it was decided to carry this passage through a small Deublin joint located on top of the shaker slip ring assembly and to eliminate it from the main rotary joint. A redesign of the slip ring assembly was made and the necessary parts were manufactured and shipped to Huntsville with the rotary joints. Because of the airline strike at this time, shipment was rather slow.

Some time was spent on modernizing "as built" drawings for submittal and work was commenced on writing and assembling the instruction manual.

July 1966

Installation was completed after arrival of the rotary joints. A new inspection door was added at the side of the bearing power unit since the end door was not very accessible. Wiring and piping were almost completed.

The machine base was grouted in place. Most of the manual rough draft was completed and "as built" drawings were submitted to NASA.

August through November 1966

The system was charged with oil on November 9th 1966 and checkout of the system commenced.

Because the machine is a sophisticated one with many interlocking functions, quite a number of problems were encountered during this period. Modifications were made in the field by Rucker personnel as the problems arose so that the checkout and performance test periods cannot be chronologically separated.

With the exception of two periods (Sept 9th to Sept 26th and Oct 28th to Nov 8th) when Rucker personnel returned to Oakland for new parts etc., checkout and modification work continued until Nov 22nd when the machine was submitted to NASA for acceptance. Highlights of machine performance and problems overcome can best be listed under their respective headings.

Bearing System

Basically the bearing system consists of the main axis thrust and radial hydrostatic bearings and the shaker hydrostatic bearings. All bearings are supplied with pressurized oil from a common power unit. The main axis radial bearings consist of 4 pads apiece pressurized from individual orifices contained in a common manifold. Oil to the thrust bearing is metered through a flow control valve. All of the main axis bearings drain to a common sump within the machine pedestal. An electrically driven centrifugal sump pump, regulated by a level switch in the sump, returns the oil, through a heat exchanger, to the bearing power unit reservoir at a higher level. The shaker bearings receive their oil through the main rotary joint and drain into the shaker body. A gear type extraction pump, driven by a gear type hydraulic motor returns the oil through the rotary joint and the same heat exchanger to the power unit reservoir.

The system performed as designed and had no inherent faults. However, some minor features were encountered and a few modifications were made.

These were:

a. A faulty temperature switch on the reservoir and a damaged flow switch had to be replaced.

b. Two corrections had to be made due to incorrect piping.

c. Wiring corrections had to be made for the sump pump and level switch.

d. The time delay relay for the sump pump was adjusted to a 43 seconds delay in starting the pump.

e. The thrust bearing flow control valve was adjusted upwards to compensate for oil shortage in the thrust bearing at high speeds since a sudden increase in bearing drag occurred at 190 rpm. This may have been due to oil loss caused by centrifugal action. After the adjustment was made and the rotor was properly balanced the phenomenon did not recur.

f. A cross connection was made, through check valves, between the thrust bearing supply and the braking side of the hydraulic driving motors so that oil could be furnished to the thrust bearing should power failure shut down the bearing oil power unit while the rotor is turning. Provision was also made electrically, through a relay on the tachometer circuit, so that operation of the bearing power unit STOP button (or tripping of any interlock) would first shut down the centrifuge drive power unit, followed by shut down of the bearing power unit only after the machine comes to rest. Both systems were tested adequately when the power failed several times at high speed. No bearing damage resulted. A pilot operated four way valve was added later to prevent loss of braking pressure at low speeds during normal operation.

g. A ball valve was installed in the shaker supply under the rotary joint so that the latter was not pressurized unnecessarily when the shaker was not in operation.

h. A check valve opening to atmosphere was added at the power unit to prevent syphoning of oil through the Continental pump to the pedestal sump when the system was not in use.

i. Pressure gauges were added at the main bearing pads and at the thrust bearing supply to monitor bearing action.

j. A supply pressure drop of approx 200 psi occurs when the shaker extraction pump has been running for 10 to 15 minutes. This is probably caused by aeration of the oil returning from the extraction pump (which extracts oil and air from the shaker body) and reaching the main pump suction. This is not detrimental providing the shaker oil supply remains above 650 to 700 psi. It is recommended that the oil level remains high and that the supply pressure (without the extraction pump running) is set at 1050 psi. The oil pressure has never dropped to dangerous levels as a result of this phenomenon.

k. The heat exchanger is entirely adequate. Oil temperature stabilizes at approx 92°F.

Main Drive System

The drive system consists of two Vickers hydraulic motors forming part of a closed hydraulic system serviced by a Denison Model 900 servo controlled variable volume pump. Adjustable pilot operated relief valves are used to control driving and braking pressure. The servo pump, together with a Gresen makeup pump, are driven by a common 60 HP electric induction motor.

Some doubt existed, prior to checkout, that the unusually tight fit of the rotor in the circular enclosure would require more power than was calculated and designed into the system to reach the 100G speed of 221 rpm. However, this doubt was unfounded in practice when full speed was reached with power to spare. No more than 75 amps was drawn on the motor which is rated 79 amps. The relief valve was set at 2500 psi and less pressure was used. The requirement to reach the 10 G speed (70 rpm) in 60 seconds from rest, with the loaded shaker in place, was met when the supply pressure was raised to 3600 psi. However, in reaching this performance the following problems were overcome.

a. A relief valve was originally installed between the two motors as a means for improving control accuracy at very slow speeds by minimizing backlash. This valve, unfortunately, caused the second motor to cavitate while braking. This motor was damaged by the cavitation and had to be removed and rebuilt. The internal parts of the offending valve were removed to avoid a recurrence of cavitation. It was found that control accuracy was not affected by elimination of the valve.

b. Initial troubles with sticking servo valves indicated dirt in the system. Although the pipework had been thoroughly cleaned before and during installation, this work was redone, the servo valve was back flushed and the filter was changed to a 3 micron element. When the trouble persisted the servo pump hanger control cylinders were opened up and found to contain cast iron dust from the original manufacture. The cylinders were thoroughly cleaned with alcohol and a manifold was inserted beneath the servo valve so that its drain no longer communicated with the pump body. In addition a new servo valve was obtained and a flushing plate was made to replace the servo valve while the whole system was flushed out by running the pump before replacing the servo valve. At this time a solenoid operated four way valve was paralleld(using appropriate check valves) across the servo valve so that if the latter stuck open the pump hanger could be brought to neutral by pushing the KILL button added to the control console. (A mechanical stop originally installed on the servo pump can be set to prevent overspeed from a pre-selected G level). In the event of power failure the pump hanger is also urged toward the neutral position; thus applying the hydraulic brake.

Mechanical

No trouble was experienced with the mechanical parts of the machine which performed precisely as designed. Structural parts were adequate for the forces imposed on them. (Such as the 100G test with a 500 lb payload, whose center of gravity was 15" high, mounted on the environmental table.) The main spindle was found to be vertical within $\pm$ .00075 ins per foot, and the azimuth table was levelled to $\pm$.001 inches per foot. The enclosure wall was found to be out of round by $\pm$ 1 1/2 inches variation from the mean circle.

A modification was made to the base plate and shroud to accomodate an error in the length of the foundation bolts. The plastic cover and environmental chamber were tested at 20G and found to be sound. The balance weights were stripped of paint and plated for a more pleasing appearance.

Drive Control

The servo control system was adjusted during the checkout period to improve accuracy and eliminate instability. The system consists of three stage amplification with the first stage being one of integration and the third stage containing a loop around the pump servo valve with pump hanger position feedback. Speed feedback from a Kearfott tachometer completes the main loop. Once per revolution speed changes (wow) were generally within specification because of the high inertia designed into the machine. It is doubtful whether pit out-of-roundness has any effect on this. Periodic steps in speed were found to be due to the sump pump starting and stopping. Inrush current caused transient voltage spikes which could not be corrected instantly. No 6 wiring was used to replace the No 12 wiring to the control console and the sump pump ceased to have any noticeable effect. Furthermore a 60 cps dither was introduced to the third stage amplifier and this eliminated the steps altogether. To refine the system as far as possible a chopper stabilized amplifier was installed for the first stage integrator and the power supplies were renewed. The transient effect had almost vanished except for an occasional spike in the incoming 110 volt supply. Excursions in speed due to these transients are quickly compensated by the system. The very slight periodic short term (about 2 minute period) variation still existing is not significant. Early in the checkout a breaking belt had disengaged and damaged the tachometer. Without a feedback signal the machine had begun to gather speed and could only be halted by stopping the hydraulic power unit. Also it was found that a sticking servo valve would cause the pump hanger to remain open so that the brake was not applied. To avoid such a happening the control console was modified to include a KILL button with relays and a reset button. This feature de-energized the solenoid valve bypassing the servo valve and returned the pump hanger to neutral, thus applying the brakes. The OFF switch was also changed to bleed off the integrator and dissipate the speed command so that, in the absence of a feedback signal, the machine would stop when the switch is turned to OFF. It is still necessary to set the pump mechanical stop to prevent the possibility of over speeding if no one is present to apply the brakes.

Some trips occurred before the bearing unit temperature switch, the oil low pressure switch, and the water flow switch were properly adjusted.

On several occasions all relays in the console tripped at the same time.

This could only have been caused by an instantaneous interruption to the 110 volt supply. To prevent this happening the power supply should be improved or else all relays and starter coils should be of the time delay type.

During the early testing the building power supply tripped on several occasions. It was found that the whole building was supplied from one 200 amp breaker. This was modified by NASA and no further trips occurred.

Speed Readout

The counter worked satisfactorily from the magnetic pickup device. The optimum gap setting was found to be .007"- .008". The counter sensitivity worked best at the 1 volt RMS setting. Higher sensitivities picked up pulses from the surroundings and interpreted then as extra teeth. Connectors were installed on the magnetic pickup - tachometer assembly in the field for ease of removal.

Azimuth Table Drive

The constant azimuth table, though specified for use up to 10G's was originally planned to run unloaded at 100G's to avoid de-clutching the timing belt which drives it from a fixed pulley at the centrifuge axis. Belt tension is adjusted by two pairs of idlers mounted in guides and riding on left hand - right hand screws. Three belts were originally furnished (2 spares).

When first bringing the machine up to speed the belt rode up over the idlers and broke loose at 160 rpm. On riding over the inner pulley the belt got tangled up in the tachometer assembly.

Aluminum flanges were made for the idler pulleys and a new belt was installed. The tachometer was replaced before the machine was again brought up to speed. At 164 rpm the second belt broke cleanly and there was evidence of damage to the azimuth table tapered roller bearings. On dismantling the azimuth table it was found that the upper bearing retainer clearance had been omitted and the retainer had been rubbing on the housing. The rollers and bearing cup were also badly galled; probably due to chips generated by the retainer rubbing. In addition it was found that the hex head screws holding a seal retainer in place had been interfering with the top surface of the aluminum pulley. Each screw head had collected a lump of aluminum gathered around it. The assumption is that the lumps acted as sprags and had jammed between the bolt head and the pulley causing belt breakage. Neither the belt nor the bearing had been loaded to anywhere near the rated limit under normal conditions.

The upper bearing and the oil seals were replaced. The pulley was cleaned up and counterbored nylock socket head screws were used in place of the hex head screws to leave at least 1/8 inch clearance. The last of the three belts was installed and the table was re-assembled. In addition a segmented ring was made for disengaging the belt from the center pulley at speeds greater than 70 rpm (10G) so that no chance of breaking the last belt would exist. A flange was installed on the center pulley to partition the belt compartment from the tachometer assembly.

Inboard and outboard synchros were mounted to record the dynamic instantaneous rotational displacement between the azimuth table and the main arm. After minimizing synchro backlash and run out it was found that the position variation was within the specification of plus or minus six minutes of arc for a balanced load. An accelerometer mounted on the edge of the azimuth table was used to record any variations of acceleration from a true sine wave in order to test for table oscillation.

Balance Indicator

The differential pressure gauge connected across opposing bearing pads performed well in its function of indicating machine balance (or unbalance). For tests in the 20G range, precise balancing is not necessary but for speeds over 150 rpm the machine must be balanced quite well to avoid bearing drag. Bearing drag was experienced at about 190 rpm when an attempt was made to run with quite a large unbalance. Proper balancing eliminated this. It was found that, due to the well lubricated bronze bearing material, even when metallic contact did occur the drag was sufficient to slow machine speed to safe limits without bearing damage so that an inherent safety feature exists. A gauge oscillation that occurred at 190 rpm was eliminated by adjustment of the needle valves in the gauge lines.

Shaker

The shaker itself performed without trouble as designed. It was tested time and again over the 10-2000 cps range with 20G vibration imposed on a 100 lb test weight. These tests were performed in the horizontal and vertical modes, with and without centrifuge rotation up to 100 rpm (20G+) and with and without a vacuum in the chamber under all conditions. The test runs were also made after prolonged CO_2 injection into the chamber followed by the creation of vacuum. Random vibration spectrums were also imposed on the loaded shaker under most of the above conditions.

Some of the minor problems overcome were:

a. An error in hose connections when installing the shaker to the rotor caused oil to enter the water system and water to enter the oil. This necessitated a complete change of oil in the bearing system. The hose ends have now been color coded to prevent this happening in the future.

b. The check valve connecting the interior of the shaker body to the space above the armature was removed and the hole was plugged. The check valve was originally planned to allow the extraction pump suction to partially compensate for vacuum above the armature and allow the gas compensation pressure to be lowered when resisting both vacuum and 20G acceleration horizontally on the 100 lbs weight. However, with a 3 psi spring in the check valve the resulting 3 psi suction in the shaker body due to the extraction pump was sufficient (in the absence of a vacuum chamber above) to draw the armature down to its lower over-travel switch and leave no room for vibration. Using a lighter spring solved this problem but allowed leakage of oil into the chamber when the vacuum was released in the chamber before the extraction pump was stopped. A bleed valve on the end of a hose was used instead of the check valve. This valve will always be open unless combined vibration and vacuum are needed on a heavy specimen in a high axial acceleration field.

c. The pressure switches initially installed in the shaker to monitor bearing oil pressure were unreliable and did not last electrically or hydraulically. These have been replaced by a single large diaphragm type pressure switch at the shaker inlet.

d. Vacuum leakage occurred through the top seal fastening and from a virtual leak from an annulus under the upper tiebolt washer. The sealing surface to the armature was modified to use clamping wires instead of screws and the outer clamp ring was undercut for better sealing. The washer was grooved to allow escape of air from the annulus between it and the tiebolt sealing O-ring. This arrangement proved vacuum tight.

e. In reassembling the tiebolt nut after the above operation, the nut galled on the tiebolt and had to be drilled off. Two threads on the tiebolt were damaged. Although sufficient strength still remained in the threads, it was deemed better practice to replace the tiebolt. This necessitated a week's delay and a return to Oakland. The new rod was tinplated and great care was taken in cutting the threads to eliminate burrs and sharp corners. During the attempts to remove the nut after the galling, the lower gas diaphragms were damaged and had to be replaced.

Shaker System

The shaker amplifier and field supply unit performed satisfactorily. The random manual equalizer was set up and tried out by the MB representative. Three of the cable pieces connecting the shaker to the slip rings were replaced because they were a little too short. The field connectors were soldered on to the cables after the connector clamp screws proved inadequate. Some initial trouble was encountered in the accelerometer feedback loop. A fault in the source follower, which caused transistors to burn out in the accelerometer normalizing amplifier, was located and corrected. In addition the accelerometer cable and the feed through connector (Microdot) were found to be faulty. The cable was replaced and a special connector was made as an improvement over the Microdot one which was not, in any case, available for several months. The new connector was made with more vacuum tight features since vacuum leakage was also a fault of the old one.

Cooling Water System

With the exception of a faulty water regulator on the original Ling unit (this was replaced) no trouble was experienced with the cooling water system. It was found that the pressure should be set at 70 psi to close the flow switches and to open the bypass check valve on the rotor when the shaker is not installed. The system was flushed thoroughly with raw water before filling with distilled water.

Gas System

This system performed well with no major problems. the 20G horizontal test uses a lot of gas and necessitates (as expected) recharging each time the test is rerun. Eventually the NASA high pressure nitrogen system may be used instead of nitrogen cylinders. The gas was routed through the Deublin rotary joint by modifying the upper slip ring assembly (instead of through the main rotary joint where it was originally designed).

Vacuum System

After locating several elusive leaks the vacuum was eventually brought within the specification of 10 microns. After using a NASA vacuum gauge attached to a blank flange over the intake hole in the chamber floor , it was found that up to this point (including the rotary joint), the vacuum could quickly be brought down to 6 microns. Using the plug in place of the shaker it was found that the main leaks occurred through the accelerometer and thermocouple feed through connectors. The accelerometer connecter was replaced with a special one assembled and potted in the field and the thermocouple connector was replaced by a Cannon glass sealed one. After this the vacuum (with plug instead of the shaker) was brought down consistently to 6 microns. The shaker was then installed and leaks were located and repaired in the seal as discussed before. The connector on the vacuum transducer was replaced with a tighter one since erratic readings were registered due to the original connector being too loose. The solenoid valve in the vacuum line was rewired to a separate switch on the console so that the vacuum could be released from the control console. Oil in the CO2 line caused some delay when the chamber gasket became oil saturated after injection of CO2. The gasket had to be renewed.

CO2 System

When first tried out, oil was found in the pipeline. The line was flushed out and blown with air. Liquid CO2 was sprayed directly on to a small aluminum block attached to the 100 lb steel weight with a thin rubber washer between them. The thermocouple was mounted on top of the aluminum block. The steel block was raised on epoxy stand-offs above the shaker table. The temperature dropped rapidly at first and then leveled off as heat flow into the steel block equalled heat flow into the aluminum. Two cylinders of CO2 were used. Much more would be required to lower the temperature of the steel block appreciably. In actual experiments the specimen would be set up and insulated to best advantage for the test required. The 100 lb steel block was used in this case because it represented the specified maximum load on the shaker. Vacuum was drawn on the cold specimen, the centrifuge was accelerated to 20G's and combined acceleration, vibration, vacuum and cold temperature tests were run satisfactorily. Creating a vacuum before injecting liquid CO2 prevents ice build up on the CO2 nozzle.

Rotary Joint

The rotary joints performed satisfactorily after the high pressure gas was diverted through the Deublin joint. In particular the vacuum pass had no detectable leakage and could hold 6 microns. The main rotary joint kept reasonably cool with the water passing through it. The azimuth table joint reaches about 130°F at speeds up to 70 rpm. If higher speeds (not recommended because of the belt) are used in the future the azimuth rotary joint should be water cooled.

The main rotary joint was dismantled as a check after considerable running and the quad rings were found in good condition. They were changed, (on principle) and the joint was regreased and reassembled.

Slip Rings

Both instrumentation slip rings were used in series when recording accelerometer measurements from the azimuth table. Noise was not excessive. The shaker slip rings adequately carried the shaker current with minimal attenuation. The shaker slip ring assembly was modified to accept the Deublin rotary union and the pipe leading from it. An initial wobble problem was eliminated by careful alignment and by using a softer hose coupling to the centrifuge.

The high frequency wave guide loss was approx 4 db after an initially high reading due to a faulty connector which was replaced.

Television System

The television camera provided a very clear picture at all speeds. The cable connecting the camera to the control unit was originally too stiff. This caused wires to break away from the connectors when bent. The cable was remade in the field using a looser construction.

December 1966

During this month the manuals were prepared and submitted, the drawings were corrected and resubmitted and the final report is now presented.